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Integration of Seismic and Resistivity Methods to Map the Distribution of Oil Sand Bodies and Water Sand Channels in the McMurray Fm: Mineable and SAGD Case Studies

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EXTENDED ABSTRACT

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High-resolution geophysical methods capable of imaging the subsurface geology in three-dimensions are proving to be important tools for the delineation of bitumen-rich zones and water saturated channels in the McMurray Formation of Northeast Alberta. At an operating oil sands mine the feasibility of water disposal in the basal water sands of the McMurray Formation was investigated. Seismic reflection data, collected originally for oil sands delineation, was supplemented with drilling, seismic, resistivity, and borehole logging surveys to map the sand channels. Isopach maps of the basal water sand and structural contour maps of the Devonian limestone surface delineate a channel that is the target for the horizontal wells. At in-situ steaming operations (Steam Assisted Gravity Drainage) the horizontal well pairs must be located in the zones that can exploit the maximum connectivity between bitumen saturated sections of the McMurray Formation. Characterizing the geological complexity of the McMurray Formation (channel geometry, shale lenses, Devonian collapse features) is commonly done using a dense pattern of exploration wells. Geophysical methods offer a more cost-effective way of targeting the exploration wells to maximize the

information derived and minimize the surface disturbance. High-resolution seismic data (2D and 3D) can be used to effectively map the structure of the McMurray Formation and underlying Devonian units. Non-seismic methods such as resistivity and electromagnetic imaging can be used to derive physical properties that relate to porosity, bitumen saturation, and pore water salinity. For both steaming (100 – 300 m) and mineable (< 50 m) depths, a combination of vertical exploration wells, seismic reflection, and 2D electrical imaging is currently being used to reduce exploration risk. Future developments include imaging between vertical and horizontal boreholes and time-lapse imaging of steam fronts.

INTRODUCTION

The Athabasca oil sands in NE Alberta (Canada) are one of the largest deposits of bitumen in the world (Figure 1). The bitumen resides in unconsolidated Cretaceous sands at depths of between 10 m and 400 m below ground surface. The mineable deposits (< 50 m depth) comprise only 10% of the total volume of oil sands. The remaining 90% (over 189 billion m^3 of oil), require the application of in-situ recovery processes such as Steam Assisted Gravity Drainage (SAGD) to yield economical reserves. Over 65% of the deposits have an average pay thickness greater than 15 m. The McMurray Fm is a predominantly continental sequence of uncemented sands and shales unconformably overlying Devonian marl and limestone with highly variable relief. The overlying Clearwater Fm and Grand Rapids Fm are interbedded silts and clays. Geophysical methods including borehole logging (Figure 2) and seismic reflection surveying (Siewert *et al*., 1998) have been the mainstay of exploration programs for both the shallow and the deeper deposits. In the last 10 years, geophysical methods such as transient electromagnetics (TEM), airborne magnetics, and DC-resistivity have been tested on the oil sand leases.

CASE STUDIES

In two recent programs, approximately 100 line-km of 2D electrical resistivity tomography (ERT), and 2D high-resolution seismic data were collected to map oil sand and water sand channels.

Case Study 1: Water Sand Mapping for Oil Sand Mining

In mineable deposits the basal McMurray Fm water sand unit is important from the perspective of mine dewatering and water disposal. On a typical lease, seismic reflection data were used for exploration of the oil sand and Devonian surface. During the planning of the mine and tailings facilities, the data were reinterpreted to map the water sand channels (Figure 3). Additional resistivity imaging lines were collected to map the channel, from under the proposed tailings pond towards the Athabasca River. Using all available data, a three-dimensional model of the channel was developed for a groundwater modelling exercise.

Case Study 2: Oil Sand Mapping for SAGD Operation

Many oil sand leases north of Fort McMurray extend from low-lying regions, adjacent the Athabasca River, to elevated areas. On these leases the depth of the oil saturated McMurray Fm can vary from as shallow as several tens of metres, to greater than 200 m below ground surface. In the second case study, a SAGD prospect was investigated using deep electrical resistivity imaging. In addition to the resistivity data, induction logs were available from borehole geophysical surveys across the site. The resistivity data covered areas with oil sands at depths between 120 and 150 m. The bitumen-rich McMurray Fm is electrically resistive. The overlying Clearwater shales and underlying Devonian marls are conductive. Inversion of the 2D resistivity data was performed firstly with no constraints, and secondly with constraints on the Devonian units (Figure 4). The unconstrained inversions show the general trends in resistivities of the deeper units but cannot resolve the McMurray Fm. The data were inverted with the resistivity and depth of the Waterways Fm, and Slave Point Fm/Methy Gp fixed. All other parameters were allowed to vary freely (Loke and Barker, 1996). Constrained inversions emphasized the lateral resistivity variations of the McMurray Fm above the constrained horizons. Zones of increased resistivity are interpreted to be thicker or more bitumen-saturated oil sand channels.

REFERENCES

1. Loke, M. H., and Barker, R. D. 1996. Rapid Least-squares Inversion of Apparent Resistivity Pseudosections by a Quasi-newton Method. *Geophysical Prospecting*, 44, 131-152.

2. Siewert, A., Millington, G., and Wilkinson, K., 1998. High Fidelity Vibratory Seismic "HFVS" Application for Shallow Heavy Oil Sand targets – Kearl Oil Sands Mine 2D Survey and Cold Lake 3D Survey Alberta. Extended Abstract, Geotriad Conference, Calgary.

FIGURES

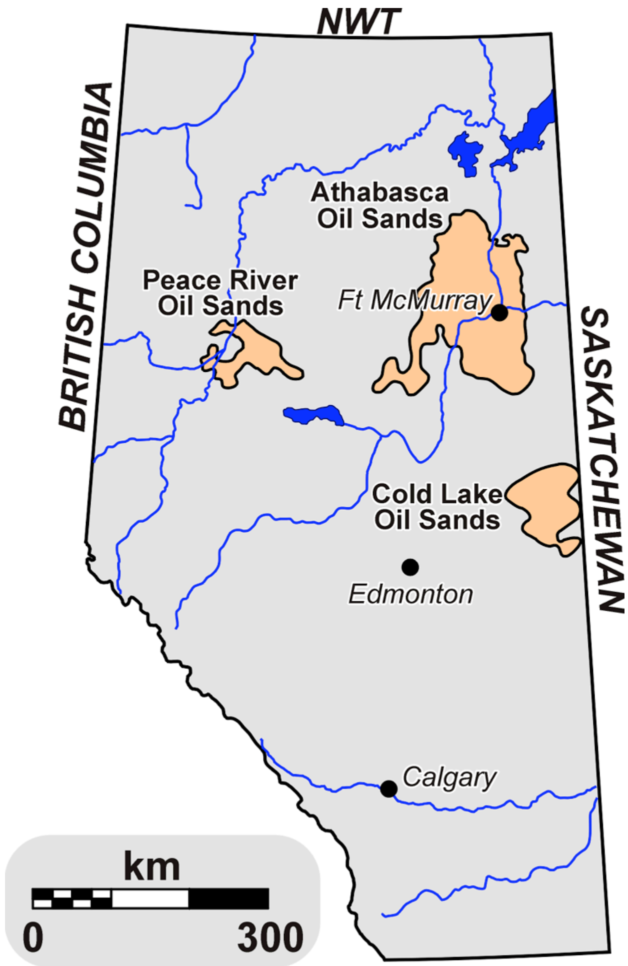

FIGURE 1. Oil sand deposits in Alberta

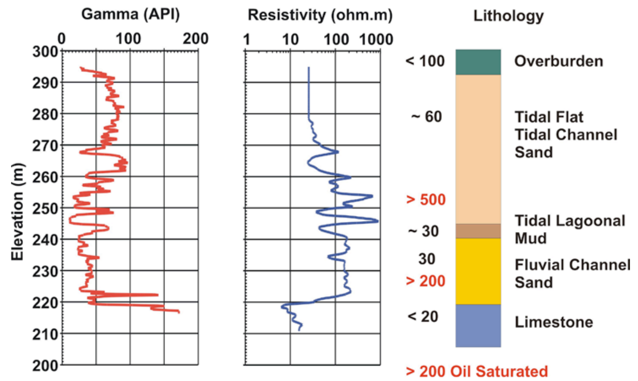

FIGURE 2. Geophysical borehole logs of a typical McMurray Fm oil sand section.

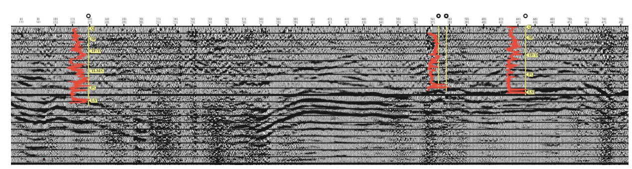

FIGURE 3. High-resolution Seismic Reflection Section of a McMurray Fm water sand channel. The strong reflector is the Devonian Limestone.

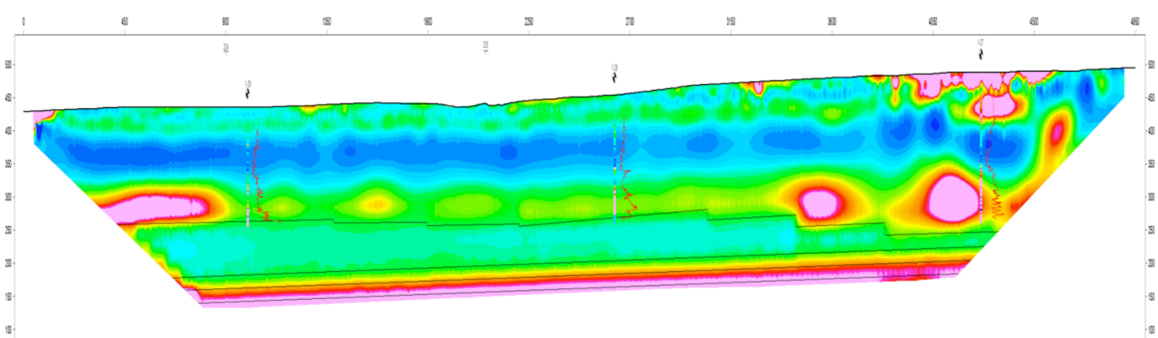

FIGURE 4. Deep Electrical Resistivity Imaging Section of a SAGD target. Blue colors are shales and clays with resistivities less than 10 ohm.m; green colors are silts and marls (10 – 30 ohm.m); red colors are surficial gravels, McMurray Fm oil-saturated sands or deep Devonian carbonates with resistivities greater than 100 ohm.m.